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Ant species accumulation on Lord Howe Island highlights the increasing need for effective biosecurity on islands

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Abstract

Islands are particularly noteworthy for global conservation because of the high number of species they host, the high levels of species endemism, and the large number and proportion of species at risk of extinction. Much of the conservation threat on islands is from invasive species. Whilst biosecurity is an increasing focus of attention for authorities globally, species are continuing to establish in new locations outside of their native ranges. Among invasive species, ants are a prominent taxon, especially on islands. Over the past decade, following the detection of one of the world's worst invasive ant species, African big-headed ant *Pheidole megacephala*, the environmental management authority on world-heritage-listed Lord Howe Island has focused attention on invasive ants. This detection influenced the creation of biosecurity measures to prevent further incursions of exotic species, particularly ants. Despite these efforts, over the following decade numerous ant species were collected on the island for the first time, indicating a serious biosecurity problem. Here, we investigate the chronosequence of ant introductions to Lord Howe Island to quantify the extent and nature of the island's ant biosecurity problem. A total of 45 species have been collected on the island and of these, 12 are considered to be endemic, and a further seven are possibly native. Nineteen of the 26 introduced species (42% of the total fauna and 73% of the introduced fauna) were only found for the first time in the last 15 years. All but two of the species that are not native to Lord Howe Island are native to the Australian mainland, indicating that the biosecurity threat comes from the transport of goods from the Australian mainland. We suggest that the pattern of accelerating ant species accumulation on Lord Howe Island is probably not an isolated phenomenon, and that it is probably occurring on most islands globally that are habitable by ants and visited by people.

Keywords

alien, biological invasion, colonisation, dispersal, exotic, invasion, introduction

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Introduction

Islands are particularly noteworthy for global conservation efforts because they host more than 20% of the world's terrestrial plant and vertebrate species within less than five percent of global terrestrial area (Kier et al. 2009). Reflecting this conservation significance, ten of the world's 35 biodiversity hotspots consist entirely, or largely of islands (Zachos and Habel 2011). Island biodiversity is highly threatened, with over half of all recent documented extinctions occurring on islands (Butchart et al. 2006; Sax and Gaines 2008), including almost 1000 species of non-passerine land birds (Duncan et al 2013). Islands currently harbour over a third of all terrestrial species facing imminent extinction. (Ricketts et al. 2005), as well as 45% of all species categorised as critically endangered by the IUCN (Baillie et al. 2004).

Much of the conservation threat on islands, as well as on mainland ecosystems, arises from invasive species, which are considered to be the second largest driver of extinction globally (Bellard et al. 2016). Among invasive taxa, ants are particularly notable for their serious environmental impacts (Holway et al. 2002; Lach and Hooper-Bui 2010), especially on islands. A prominent example is the yellow crazy ant *Anoplolepis gracilipes* F. Smith, 1857 invasion on Christmas Island that has resulted in significant environmental transformation of the rainforest ecosystem, as well as promotion of secondary invasion by other invasive species (O'Dowd et al. 2003; Green et al. 2011). The cumulative effect of these invasions has recently resulted in the first vertebrate (a bat) extinction in Australia for over 50 years (Lumsden 2009; Martin et al. 2012). Another example is the accidental introduction of about 60 ant species to the Hawai'ian islands since human colonisation (Krushelnycky et al. 2005), which has resulted in substantial negative impacts on native Hawaiian biodiversity (Reimer 1994).

Each year, more ant species are being accidentally transported by human commerce, and species already outside of their native range are further dispersing to new locations (Williams 1994; McGlynn 1999; Holway et al. 2002). Because of the significance of the social, economic and environmental effects of many ant invasions, as well as the difficulty in eradicating invasive ants after they have established (Hoffmann et al. 2011, 2016), globally, ants are increasingly becoming a target of biosecurity measures to prevent their arrival, especially on islands (HAG 2001; PIAG 2004; COA 2006). Such biosecurity measures are potentially most advanced in New Zealand, where biosecurity efforts have extended to ports-of-exit in neighbouring countries to prevent contamination of goods prior to transportation to New Zealand. This port-of-exit effort reduced ant presence in goods from 17% of containers to less than 1% (Nendick et al. 2006).

Lord Howe Island is located approximately 760 kilometres northeast of Sydney, Australia in the Pacific Ocean (S31.5545, E159.0841). The island is notably species rich, with a high level of endemism (Cassis et al. 2003) and as a result of its conservation significance, the island has World Heritage status. Exotic species are prominent on the island (Hutton et al. 2007), with rats, attributed to causing the extinction of five bird species and two land snail species, as well as being implicated in the decline of many other species (Ponder 1991; Cassis et al. 2003; Hutton et al. 2007). Rats were also believed to have caused the extinction of the Lord Howe Island phasmid, *Dryococelus australis*

(Montrouzier, 1855), until a small population of the phasmid was found on a nearby rodent-free islet (Priddel et al. 2003). Similarly, invasive plants are a major focus of on-ground conservation efforts, with management costing AUD$6.5 million over the past decade (Lord Howe Island Board 2016). In 2003, the invasive African big-headed ant *Pheidole megacephala* Fabricius, 1793 was found to be established on Lord Howe Island, and an eradication program commenced. This ant is considered to be among the worst invasive species globally (Lowe et al. 2001) partly because of its severe environmental consequences (Hoffmann et al. 1999; Wetterer 2007; Hoffmann and Parr 2008).

Following the detection of *P. megacephala*, ants became a target for biosecurity measures on Lord Howe Island to prevent further ant species introductions. Such measures included more thorough inspection of goods arriving on the island, prohibition on the importation of second-hand building materials, and strict protocols on the importation of plants and soil to the island. In addition, regular prophylactic treatments for ants commenced at the port, public awareness efforts of the issues of invasive ants were initiated, ant identification training was provided to many people. Despite these efforts, over the next decade numerous ant species were collected on the island for the first time in *ad hoc* ecological surveys indicating a serious biosecurity problem. Here, we investigate the chronosequence of ant introductions to Lord Howe Island to quantify the extent and nature of the island's ant biosecurity problem.

Methods

A timeline of species discovery was generated by determining the earliest collection date of all ant species found on Lord Howe Island. These dates were identified from the labels of specimens in the ant collections of the Australian Museum in Sydney, the Australian National Insect Collection in Canberra and the Tropical Ecosystems Research Centre (TERC) in Darwin. These three collections contained the most comprehensive set of ant specimens from Lord Howe Island. They included specimens arising from both formal and informal collections by many people over the past century, commencing in 1915.

Species nomenclature follows Bolton (1995), and subsequent revisions (Seifert 2008; Ward et al. 2014). Species were designated as endemic, possibly native or exotic (introduced) based on current biogeographical knowledge of each species, and in a few cases by subjective opinion of the authors. Subjectivity exists for two reasons. Firstly, it is difficult to ascertain whether some Australian mainland species were present on Lord Howe Island at the time of the first ant collection in 1915 because they had previously dispersed there naturally, or because they had been accidentally introduced by early colonists. Secondly, ant taxonomy is far from complete, and multiple recent reviews have found that species considered to be widespread exotic species were actually multiple cryptic species, consisting predominantly of native species within their home ranges (Seifert 2003, 2008; Bolton 2007). The Australian ant fauna is particularly diverse with many cryptic species (Andersen et al. 2013, 2016; Andersen 2016), and we believe that two apparently widespread tramp species on the island may instead be cryptic species endemic to Lord Howe Island.

Results

Information obtained from entomological collections revealed that ant species were collected for the first time on Lord Howe Island during two concerted ant biodiversity sampling events in 1915 and 2003, and six smaller-scale samplings 1966, 1979, 1995, 2000, 2005 and 2012 that were predominantly opportunistic hand collections. A total of 45 species have been collected (Table 1, Figure 1), and of these, 12 species are considered to be endemic, and a further seven possibly native as they may have self-dispersed to the island prior to human colonisation. All species of uncertain provenance that we consider to be possibly native were found in the first collection in 1915. The last endemic species to be found for the first time was a species of *Discothyrea*, found in 2000. Nineteen non-native species (42% of the total fauna) were only found for the first time since 2000. All but five of the species that are not native to Lord Howe Island are native to the Australian mainland. The five non-Australian mainland species are: *Tetramorium bicarinatum* which is believed to be native to SE Asia (Wetterer 2009), *Pheidole megacephala* which is native to Africa, *Cardiocondyla nuda* which is native to tropical and sub-tropical Pacific, *Iridomyrmex albitarsus* which is native to Norfolk Island (Shattuck 1993) and the other species, *Paraparatrechina* sp, B is only known from the TERC collection from New Caledonia. Prior to 2003 there were no *Pheidole* species collected on Lord Howe Island, but since then five species have been collected, including the highly invasive *P. megacephala*. *Rhytidoponera victoriae* was first found in 1966, and *Pheidole* sp. group C in 2005, and these two species are now among the most commonly collected ants on the island (B Hoffmann, per. ob.).

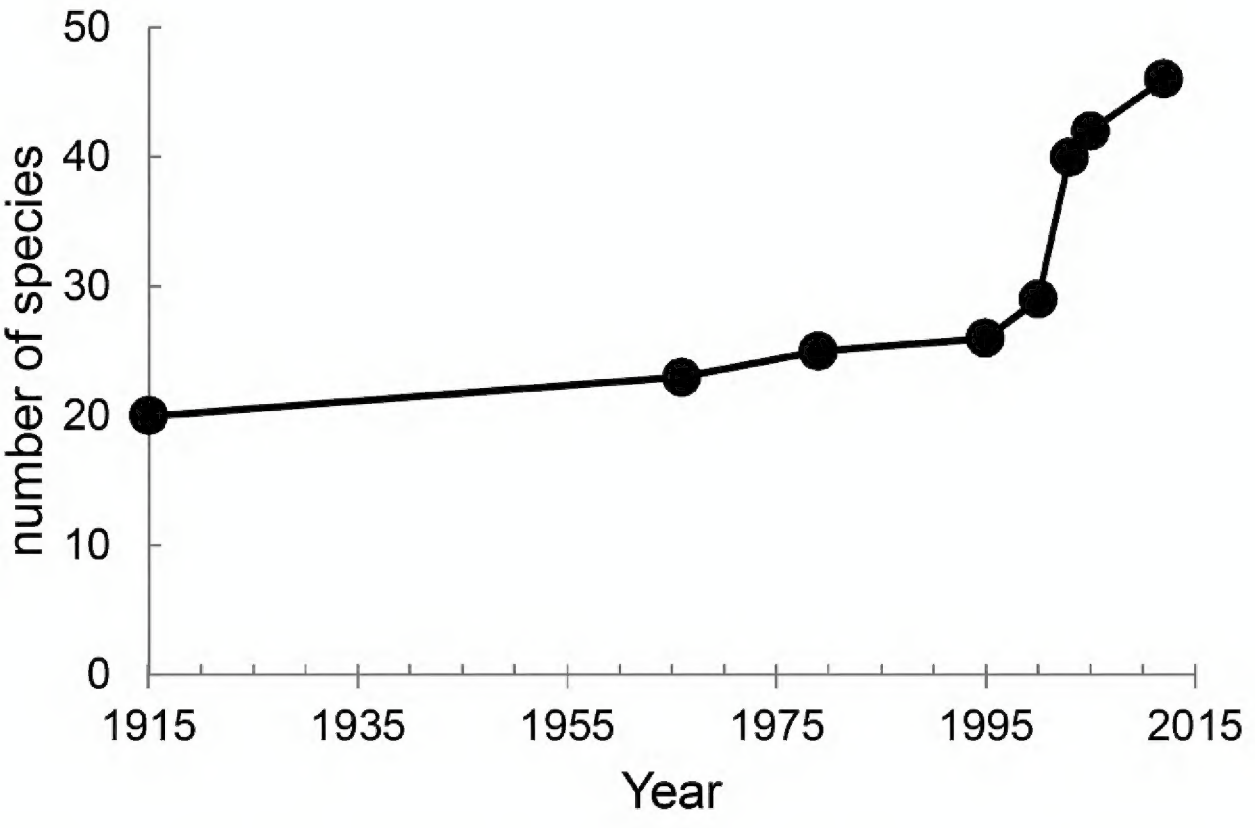

Figure 1. Accumulation of ant species on Lord Howe Island. Note that species considered to be native to the island are all graphed at 1915 irrespective of when they were first found.

Table 1. Species list of the ants of Lord Howe Island with date of first record and biogeographic origin. * indicates species that the authors believe may have a taxonomic issue in that these species may instead be cryptic species native to Lord Howe Island.

Species	Year first recorded	Origin
Amblyopone australis	1915	endemic
Amblyopone leae	1915	endemic
Camponotus howensis	1915	endemic
Cardiocondyla nuda	1915	exotic
*Hypoponera pallidula**	1915	endemic
Lordomyrma leae	1915	endemic
Monomorium sp. A *nigrius* group	1915	Possible native
Monomorium tambourinense	1915	endemic
Nylanderia sp. *obscura* group	1915	Possible native
Ochetellus glaber	1915	Possible native
Orectognathus howensis	1915	endemic
Paraparatrechina sp. A *minutula* group	1915	Possible native
Strumigenys perplexa	1915	Possible native
Technomyrmex jocosus	1915	Possible native
Tetramorium bicarinatum	1915	exotic
Iridomyrmex albitarsus	1966	Norfolk Island
Paraparatrechina sp. B	1966	exotic
Rhytidoponera victoriae	1966	Australian mainland
Stigmatomma sp. A *saundersi* group	1966	endemic
Carebara sp.	1979	Australian mainland
*Ponera leae**	1979	endemic
Proceratium sp.	1979	endemic
Stigmatomma sp. B *saundersi* group	1979	endemic
Tapinoma sp. *minutum* group	1979	Australian mainland
Camponotus sp. *novaehollandiae* group	1995	Australian mainland
Discothyrea sp.	2000	endemic
Doleromyrma sp.	2000	Australian mainland
Strumigenys xenos	2000	Australian mainland
Technomyrmex jocosus	2000	Australian mainland
Anonychomyrma sp. *nitidiceps* group	2003	Australian mainland
Crematogaster sp. *queenslandica* group	2003	Australian mainland
Iridomyrmex sp. *rufoniger* group	2003	Australian mainland
Iridomyrmex sp. *vicinus* group	2003	Australian mainland
Meronoplus minor	2003	Australian mainland
Monomorium sp. *laeve* group	2003	Australian mainland
Pheidole megacephala	2003	exotic
Pheidole vigilans	2003	Australian mainland
Pheidole sp. A *pyriformis* group	2003	Australian mainland
Pheidole sp. B *pyriformis* group	2003	Australian mainland
Pheidole sp. C *pyriformis* group	2003	Australian mainland
Tetramorium sp. *striolatum* group	2003	Australian mainland
Pheidole sp. group C	2005	Australian mainland
Monomorium sp. B *nigrius* group	2012	Australian mainland
Paraparatrechina sp. C *minutula* group	2012	Australian mainland
Rhytidoponera chalybaea	2012	Australian mainland

Discussion

Since humans started visiting Lord Howe Island in 1778, and subsequently colonised it in 1834 (Hutton et al. 2007), the island's ant fauna has increased by almost 250%, with almost three quarters (73%) of the colonising species being collected for the first time only in the last 15 years, mostly just prior to when new biosecurity measures were implemented. Importantly, although we are unable to provide any information about sampling methods and intensity throughout the last century of ant collecting on the island, there probably has not been an increase in survey intensity in the last two decades driving the recent rise in species detections. Instead, it is more likely that the increased rate of colonisation was driven by the increase in tourism and development on the island in the mid-20th century, coupled with a time-lag between when species established and when they were first detected. The global spread of exotic species is known to be positively related to economic activity through the movement of goods (Essl et al. 2011), and species will often be present for many years before their populations reach detectible levels (Vanderwoude et al. 2003; Frieire et al. 2014; Wylie and Peters, in press), especially if people are not actively surveying for them. It is most likely that some of the species found only in the past 15 years probably had been present for up to a decade or more prior to being collected; long before any biosecurity measures were established.

Since 2003, approximately coinciding with the detection of *P. megacephala* on Lord Howe Island, the movement of many high-risk items such as soil, plants, machinery and building materials to the island has been highly regulated. For example, plants must be soil free (except for a potting medium) and certified to be free of pests and disease, timber must be dressed, and gravel/roadbase must be certified to be Virgin Extracted Natural Material and free of pests. Additionally, there are enhanced protocols such as the prophylactic baiting at the wharf and immediate surroundings just in case ant species arrive in goods. But are these protocols preventing new ant incursions? As a demonstration that the relatively new biosecurity protocols are working, on 23 July 2016, as a result of compulsory inspection of all high-risk goods arriving on the island, ants were found for the first time arriving in cargo (Andrew Walsh and Hank Bower personal communication). Two intact colonies of mainland Australian species, *Polyrhachis femorata* and a *Crematogaster* species in the *laeviceps* species group, were found within timber. The cargo was rapidly quarantined and the colonies were treated with a toxic solution. Although it was clear that the biosecurity protocols worked in this instance, such protocols are unlikely to be perfect. Indeed more recently on 15 March 2017, a resident reported ants infesting a recently delivered consignment of corrugated iron. To further reduce this risk, the island's biosecurity procedures are planned to be enhanced in the latest review of its biosecurity strategy, including compulsory inspections of all goods arriving on the island, and these inspections being conducted in a more routine way. Only with more time, potentially a decade, will it be possible to demonstrate that the biosecurity measures are preventing further ant introductions.

Even if the exact introduction date of all species found for the first time in the past two decades was known, the general pattern of recent increase in species accumulation

would stand, at least up to the point of biosecurity implementation. Such an accelerating colonisation pattern of Lord Howe Island by ant species is greatly concerning. This finding begs the question, that if such species accumulation has occurred recently on such a small island associated with a mainland with a big biosecurity effort, what is happening elsewhere throughout the world where biosecurity is not such a focus? Few data are available for invertebrates globally, but very recently it has been shown that the establishment of alien insect species has nearly doubled over the last few decades in Europe (Roques et al. 2016). Even in Antarctica, strong biosecurity measures have not prevented the unintentional transport of invertebrates and plant propagules to the region (Chown et al. 2012; Houghton et al. 2014). It is suggested that what has happened on Lord Howe Island is probably not an isolated phenomenon and that many ant species are currently being accidentally dispersed to, and successfully colonising, most islands globally that are habitable by ants and visited by people (Herrera et al. 2013; Moreau et al. 2014; Morrison 2014). Indeed, even in Hawaii where biosecurity now focuses on ants, and it was reported that ant species accumulation was decelerating (Krushelnycky et al. 2005), it is now believed that there are up to 64 species present (Paul Krushelnycky, personal communication), indicating a rise in species accumulation in the past few decades in accordance with increasing commerce.

We have a poor ability to manage or eradicate most exotic species after they establish anywhere, and this is particularly the case for ants. In the most recent global review of ant eradications, there have only been 106 successful eradications (excluding 38 that were nearing the end of their 2-year monitoring phase) from 316 attempts, and 77% of these successful eradications covered less than 5 ha (Hoffmann et al. 2016). Clearly, preventing ant species colonising new locations is far more effective biosecurity measure than trying to eradicate, or even manage, them after they arrive.

The potential impacts that most of these species will have on people and the ecosystems on the island is unknown. Although the detrimental, and often severe, impacts of some invasive ant species are well known (Holway et al. 2002), just as for all taxa that are being accidentally transported to novel locations, it is completely unclear what effect, if any, most species may have (Simberloff 2011). Of all the non-endemic ant species on the island, only one, *P. megacephala*, is known to have serious negative impacts, which is why it is currently subject to an eradication campaign, and three other common tramp species, *Cardiocondyla nuda, Ochetellus glaber* and *Tetramorium bicarinatum* are known only as minor pests (Lester et al. 2003; Heinze et al. 2006; Wetterer 2009). For the other species that are exotic to Lord Howe Island there is little information that can used to predict their impacts on native flora and fauna. Most of these species are uncommon and have low abundance, with the exception of two recently arrived ant species, *Pheidole* sp. A and *Rhytidoponera victoriae* which are widely distributed in the lowland areas associated with human habitation, (B Hoffmann, personal observations). Given that ants are well documented to have major contributions to many ecosystem processes (Del Toro et al. 2012) these two species are likely to be influencing ecosystem processes on the island.

Notably, of the ant species on Lord Howe Island only five are not of Australian origin, clearly demonstrating that the biosecurity risk to the island comes primarily

from the transport of goods from the Australian mainland. Indeed it is also most likely that three of the five non-Australian-mainland species, *Cardiocondyla nuda, Tetramorium bicarinatum* and *Pheidole megacephala* were accidentally transported to Lord Howe Island from the Australian mainland. Given that we are unaware of *Paraparatrechina* sp, B and *Iridomyrmex albitarsus*, being on the Australian mainland, these are possibly the only species that arrived on the island from a different source location, most likely being New Caledonia and Norfolk island respectively. Also noteworthy is the absence of other exotic ant species that are common throughout mainland Australia that have not yet been found on Lord Howe Island, including the highly invasive Argentine ant *Linepithema humile*. It is unclear if this absence is merely due to lack of dispersal opportunity or colonisation failure. Additionally, Lord Howe Island has not been colonised by many other highly invasive ant species that occur on islands throughout the Pacific, such as multiple fire ant species, *Solenopsis* spp., yellow crazy ant, *Anoplolepis gracilipes*, and the little fire ant *Wasmannia auropunctata*. It is suggested that this outcome is not due to current biosecurity protocols, but instead reflects a lack of transport pathways to Lord Howe Island from infested locations throughout the Pacific. Essentially Lord Howe Island has just been lucky.

In summary, since human settlement there has been a significant number of ant introductions to Lord Howe Island, and it appears that species accumulation on the island has accelerated in the last few of decades. It remains to be seen whether biosecurity protocols that were first implemented on the island just over a decade ago have indeed succeeded in slowing the rate of, or even completely stopping, accidental introductions. No system is perfect, and, for example, even in New Zealand and the Australian mainland where there are stringent biosecurity protocols, incursions and establishment of many taxa are a constant occurrence. If this pattern of species accumulation on Lord Howe Island really does reflect what may be happening on islands globally, then this highlights the need for biosecurity procedures on islands to be increased, especially islands of high conservation value. Even better would be to implement more effective biosecurity measures at ports of exit to prevent transport in the first place. For both strategies, this would involve greater public awareness of invasive species generally, especially ants, as well as solid understanding of how to prevent their spread, such as by preventing the unregulated movement of soil, plant materials, machinery, construction materials and other goods, enforcement of these quarantine requirements, and high biosecurity standards at ports of exit.

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